INTERACTING BINARY SYSTEMS

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ABSTRACT

The present paper summarizes the kind of information that has been derived from ultraviolet observations of interacting binary stars and points out problems of current interest. The tasks for observations of close binary systems in the extreme ultraviolet will be discussed in a separate paper.

INTRODUCTION

In view of several recent colloquia, workshops, extensive reviews, and collections of research papers devoted to interacting binary stars, there appears to be little need for another comprehensive review of the properties of interacting binaries as revealed in their ultraviolet spectra. In addition, excellent reviews were given at previous IUE Conferences (Plavec, 1981; Dupree, 1982; McCluskey, 1982; Lambert, 1982; de Loore and Maeder, 1982).

The present paper will therefore only briefly summarize the kind of information that has been derived from ultraviolet observations of interacting binary stars, and point out problems of current interest. Comments for the tasks for observations of close binary systems in the extreme ultraviolet are discussed in a separate contribution. The present paper contains a detailed list of IUE-related papers, with titles which deal with binary star research, and which have been published in the major international astronomical journals since the last IUE Conference, and references to proceedings of meetings devoted to the same subject.

The fact that mass is transferred between the components of close binary systems and lost from the system, as well as the manner in which this is done, is of prime importance to the evolution of close binaries. The last few years have shown a continued strong interest in, and considerable efforts devoted to, the observational and theoretical aspects of this problem.

About 80 IUE related papers dealing with binary star research have been published in the major international astronomical journals in 1982 and 1983; they account for about 20% of all IUE-related publications. In addition, several extended reports or proceedings of international conferences dealing with binaries have been published since 1982.

Recently Observed Properties of Interacting Binaries

From optical photometry and spectroscopy, certain properties of individual components and the presence of circumstellar matter in close binary systems could be derived already at the end of last century. Belopolsky (1893; 1897) detected in Beta Lyrae lines whose Doppler shifts did not follow the motion of either component, and Barney (1923) observed in Algol stationary metallic (Fe, Mg) features which did not show the Doppler shifts of the photospheric lines. A pronounced asymmetry in the radial-velocity curve of the eclipsing binary U Cephei was observed by Carpenter (1930) and Struve (1944), and explained by Struve through "gas streams" within the system. These and subsequent observations, mainly in the ultraviolet spectral range with the Copernicus and especially the IUE satellites, have clearly demonstrated the observational significance of such spectroscopic anomalies. Plasma was observed which for many apparently "normal" binary systems had much higher temperatures than expected from optical observations, and which is generally ascribed to gas streaming from one star to its companion, accretion of matter onto degenerate stars, and considerably enhanced chromospheres and coronae in cooler stars.

In the ultraviolet, multiple emission lines in interacting binaries, i.e., in Beta Lyrae, were for the first time extensively studied by Hack, Hutchings, Kondo, McCluskey, Plavec, Polidan, and others (1975 and subsequent papers). Chapman (1980) reported the first spectroscopic detection of ultraviolet emission lines during the eclipse of Zeta Aurigae. Data on this still mysterious and fascinating binary, and its analysis, belong clearly to the highlights of recent IUE observations.

Zeta Aurigae is the prototype for a group of eclipsing binary systems that consist of a late-type supergiant star and a much smaller, early-type companion. Before and after total eclipse, the light of the companion passes through the extended atmosphere and wind plasma of the supergiant in what is called an atmospheric eclipse.

Chapman (1981) and Ahmad, Chapman and Kondo (1983) have derived a model of the K-star wind, far from the K-star, and its interaction with the B-star. They find a mass loss rate from the K-star of 2×10^{-8} $M_\odot$ yr^{-1}. The rate of accretion by the B-star of material from the K-supergiant is such that the matter accreted in the course of about 10 years is of the order of the total mass of the photosphere of the B-star.

The problem of mass transfer in interacting binaries was during the last several years extensively investigated by several authors. Very detailed studies of a number of different objects have been carried out by Kondo and co-workers; typical examples include Beta Lyrae, U Cephei, UW CMa, and many other systems where especially high resolution IUE spectra reveal the occurrence of mass loss of several 10^{-6} $M_\odot$/year, and loss of angular momentum, often causing a strong period decrease of the order of $\dot{p}/p$ 2×10^{-5}/year.

The expanding gas in Beta Lyrae, e.g., appears to be divided into two regions: a "chromospheric" region with T 10^4K, N_e 10^{12} cm^{-3} which gives rise to the low ionization lines; and a "coronal" region with T 10^5K, N_e 10^{10} cm^{-3} which gives rise to the high ionization lines.

But in spite of such obviously very successful observations and interesting results, I think it is safe to say that the interpretation of the photometric as well as spectroscopic anomalies observed from the ground and in the ultraviolet with the IUE often still present major intriguing problems.

In many binaries, several unusual features are discovered, such as those revealed in the very unusual spectrum of the close binary R Arae, as discussed by Kondo and McCluskey (1983). The outside-eclipse ultraviolet continuum flux varied by more than a factor of 2 in 10 days, and by more than 50 percent within the same orbital cycle. The resonance lines of C II, Si IV, Si II, Fe II and Mg II have P Cygni profiles; their emission component strengths vary with time, while the absorption components reveal both orbital and non-orbital velocity variations. Einstein (HEAO-2) satellite data show this system also to be an X-ray source.

Another very unusual ultraviolet spectrum was reported by Parsons et al. (1983) for HD 207739; it showed abnormally strong and numerous absorption features in the far-UV, and exceptionally strong Mg II emissions. While for R Arae there are as yet no corresponding ground-based observations available, HD 207739 showed very similar phenomena also in the visible spectral range (Kondo, 1984).

Symbiotic stars, Wolf-Rayet binaries and related objects continued to be under close scrutiny, e.g., by Michalitsianos et al. (1982); Sahade et al (1984); Willis (1983); and others; but the complexity of their UV spectra is such that additional observations and interpretations are clearly needed.

Evidence for a high temperature accretion region in Algol-type binary systems was pursued by Peters and Polidan (1984); they observed strong absorption lines of N V, C IV, etc. in the UV spectra of Algol primaries whose photospheric temperatures are much too cool to form such ions.

Anomalies in Zeta Aurigae (Chapman, 1981), Zeta Aurigae-type systems, γ^2 Velorum (Sahade et al., 1984), of UW CMa and other early-type systems (Dupree, Heap, Hutchings, Koch, Plavec, et al.) were interpreted as the effects of winds in these systems.

Winds are considered as the energy source for X-ray emission in massive binaries as a consequence of the interactions of an early-type and a degenerate star (Cyg X-1), of a late type star and a white dwarf (AM Her), or of a normal and a degenerate star (Her X-1).

Special attention is required for systems like Beta Lyrae and Plavec's W Serpentis stars (SX Car, RX Cas, W Ser, U367 Cyg, etc.). According to Plavec (1981), the UV radiation in these systems comes probably from a region which is much smaller than the observed surface and is associated with accretion.

W Serpentis systems have relatively large dimensions, the secondary component is, however, rather small; the outflowing matter has a large angular momentum and forms an accretion disk, similar to the conditions in cataclysmic variables--only that in W Serpentis stars, accretion occurs by a normal B star, not a white dwarf.

A more detailed study of these W Serpentis stars requires, however, additional UV observations, especially at high resolution. Until now, no such high resolution spectrum has been obtained.

Prompted by a growing interest of Western astronomers in binary star research in China, I asked Prof. Shen Liangzhao of Beijing Astronomical Observatory, who is an expert on binary star research in China, for a brief outline of interacting binary star research in China for this meeting. Among other research projects conducted, photoelectric photometry, spectroscopy and radial velocity measurements are carried out with the Beijing 60-cm and the Yunnan 1 m Cassegrain telescopes for short-period eclipsing binaries, with emphasis on W UMa-type stars (Acta Astrophysica Sinica 2, 131; 144, 1982; IBVS No. 2274, 1983; AJ 88, 1679, 1983; etc.); of RS CVn-type binaries; and of long-period binaries during eclipse. The observations are complimented by theoretical studies. I should also point out that a recent report published by the Academia Sinica summarizes astronomical research presently conducted in China.

Until recently, most model computations for the evolution of interacting binaries were carried out under conservative assumptions, e.g., under the assumption that the total mass and the total angular momentum remained the same during the mass transfer phase.

Especially UV observations, however, provided extensive evidence that for a number of binaries where the primary is losing mass, a fraction of the expelled matter leaves the system.

For low-mass systems, calculations including the effects of loss of mass and angular momentum, were carried out by Plavec et al. (1973); for massive systems by de Loore et al. (1979). For massive systems, stellar wind mass losses before the Roche lobe overflow were also taken into account. The evolution of the two components was calculated simultaneously by Helling et al. (1982).

Interpretation of Spectroscopic Anomalies

Although over the years, numerous studies dealt with interaction processes, as well as with the initial conditions leading to mass transfer from one component to the other, the question of mass transfer itself, and a definite identification of escaping mass with spectroscopic anomalies is, however, still not completely and unambiguously solved (see, e.g., Plavec, 1968, Kopal, 1971, 1978, 1983; Paczynski, 1971; McCluskey, 1982). On several occasions, Kopal has commented on the problems that are involved when physical models for interacting binaries are constructed based on photometric and spectroscopic observations; he has enumerated several "caveats" arising in this connection (cf. p. 472 of Kopal, 1978; p. 555 of Kopal, 1981), some of which might also be mentioned in the present paper.

In problems characterized by very many degrees of freedom, as is the case with interacting binaries, it is virtually hopeless to try to arrive at their solution without the support of adequate physical theory.

The phenomena exhibited by close binary systems can only be interpreted in the framework of hydrodynamics (or hydromagnetics) of radiating media, and not particle mechanics. If the motions of atoms or ions which are observed in interacting binaries could be described by collisionless particle trajectories, the density of the gas consisting of such particles would be too low by many orders of magnitude for any kind of observational detection.

One should also remember that the concept of critical Roche equipotential surface as defined conventionally--and used continuously--is of significance only for equilibrium configurations, and becomes physically irrelevant in the presence of motion, or in the presence of a strong field of radiation. Respect should be paid to the Roche lobe whenever it is deserved; but its concept should not be abused and stretched to cases where it no longer applies--such as those involving gas motions, where it is the Jacobi integral which should take its place; or the Bernoulli integral in the case of fluid flow.

A loss or transfer of mass in close binary systems is related with any period changes by equations which are of vector (not scalar) form. In order to specify any period change, one needs to know not only the amount of mass involved in the process, but also the velocity and direction of escape, as well as the region of the star's surface from which the escape may take place.

Finally, before one goes too far speculating on the effects which "shells", "rings", "mass exchange," etc., may produce in the observations, one should address the questions on how, and by which process, could such formations have come into being; if they did, what their lifetime would be; what would maintain them; what would prevent their dissolution; and whether the contemplated formation would be necessary, or only optional, to produce the observed effects.

After these words of caution, we should continue in further pursuit of the goal, to better understand the origin and evolution of close binary systems--strongly supported by IUE and its superb staff, especially Drs. Boggess and Kondo here at Goddard, and Drs. Benvenuti and Wamsteker at Vilspa.

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